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Physicochemical and Technological Properties of the Starch from Corn (*Zea mays*) Variety P-7928

IVAN GONZALEZ-GONGORA[1], ARNULFO TARON-DUNOYER[2], SOMARIS ELENA QUINTANA-MARTINEZ[3] and LUIS ALBERTO GARCIA-ZAPATEIRO[3]*

[1]Department, Institute of Pharmacy and Food, University of Havana, Havana, Cuba.
[2]Department of Food Science, Faculty of Engineering. Research Group on Biotechnology, Food and Education (GIBAE). Universidad de Cartagena, Cartagena de Indias, Colombia.
[3]Research Group of Complex Fluid Engineering and Food Rheology, Universidad de Cartagena, Cartagena de Indias, Colombia.

Abstract

Starch is the main chemical component of corn grain (*Zea mays*) grain with values between 72% and 85%. The physicochemical and technological properties of corn starch are closely related to its variety and structure. The objective of this research was then to characterize and analyze the physicochemical properties of starch obtained from corn var. P-7928. The degree of hydrolysis of native and gelatinized starch was calculated. The water holding capacity (WHC) was evaluated in 2% starch suspensions heated to 60, 70, 80, and 90 ° C. The water solubility index was determined by gravimetry. Starch from corn var. P-7928 has a syneresis of 45% in 15 days; the degree of hydrolysis was 21% and that of the gelatinized starch was 98%. The maximum WHC was 50% at a temperature of 90°C and the water solubility index was 20 at 60°C. According to the results found, the starch of this variety has good properties compared to commercial starches on the market, making this variety a potential candidate for the obtaining of starch.

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Introduction

Corn (*Zea mays*) is the most produced cereal worldwide by FAO,[1] and a native grain of the current diet of Latin American.[2] The grain has a polysaccharide content, a compound with a higher starch content (values greater than 72-73%)[2] and simple carbohydrates such as sugars in the form of sucrose, fructose and glucose (1 - 3 %).[3,4]

Starch is a polysaccharide found in plant cells, that form isolated structures in the form of granules, and it is composed of amylose (25-30 % of starch)

CONTACT Luis Alberto Garcia-Zapateiro lgarciaz@unicartagena.edu.co Research Group of Complex Fluid Engineering and Food Rheology, Universidad de Cartagena, Cartagena de Indias, Colombia.

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and amylopectin (70-75% of starch). The granular structure is form with molecules organized into concentric ring,[5,6] where de distribution of amylose differs between the center and the periphery of the granules since it only occupies the available places left by amylopectin after it is synthesized.[7,8,9] Then, the structure of starch influence on the physicochemical and techno-functional properties;[2] origin and amylose/amylopectin ratio;[10–12] when its use as a food ingredient is based on its interaction's properties with water, especially its ability to form gels.

Starch is abundant in different foods such as cereals and potatoes, can be easily extracted, and is the cheapest of all substances with these properties, whereas the starch most commonly used is obtained from corn.[13] Waxy corn starch produces clear and cohesive gels, while rice starch forms opaque gels. Also, starches present different physicochemical properties, including amylose content, size, morphology, thermal properties, crystal properties, hydrolytic properties and expansive, depending of the source,[14,15] which define their use of in the food and non-food industries, and determine the quality of the product.[16] Also, it is widely used in chemist, pharmaceutical, paper, and feed industries, as well as in the textile, cosmetic, polymer, and food industries, as a primary component or food additive, an extensively utilized due to its natural origin, low cost and availability of sources, as well as its biocompatibility, safety and biodegradability.[17,18] However, its applications have been somewhat limited due to certain characteristics, including starchy taste, low viscosity, undergo syneresis and tendency to retrograde;[19,20]

Starch and modified starch present physicochemical and technological properties of interest, for example they are employed as thickeners, emulsifiers, adhesives and gels in the food industry.[21,22] Furthermore, different types of starch are widely used in chemistry, medicine, textiles, and other fields.[23]

In order to employee starch in food industry is necessary to know their physicochemical and techno-functional properties such as gelatinization, swelling, solubility, water absorption, syneresis and rheological behavior.[24] The fundamental characteristics of native starch are the molecular structure and the granule size distribution that influence their physicochemical and technological properties, such as thickening power, that influence the usefulness of starch in food and industrial applications. The objective of this research was then to characterize and analyze the physicochemical properties of starch obtained from corn var. P-7928.

Materials and Methods

Vegetal Material

The yellow crystalline corn (*Zea mays* L) variety P-7928 was harvested at the Institute of Horticultural Research "*Liliana Dimitrova*" in Cuba. Then, it was dray and the bean was stores until their use. Commercial corn starch was used as a control sample.

Obtention of Starch from Corn var. P-7928.

Starch from corn var. P-7928 was obtained by wet grinding process, which was carried out following the procedures describe by Przetaczek-Rożnowska[11] with some modifications. A suspension of flour: water (1:10 ratio) was made in a 1% sodium bisulfite solution and stirring for 4 h at 25 ºC. Subsequently, to ensure that the raw material is completely solubilized, homogenization at 650 rpm x 5 minutes. This mixture was filtered and the residue was washed with distilled water. The filtrate was centrifuged at 3000 g for 10 minutes to precipitate starch. Finally, the starch was dried at 40 °C until constant weight.

Determination of Syneresis

The starch syneresis was determinate following the procedures describe by Loubes *et al.*,[25] Briefly, Starch dispersions were prepared at 2% w/w and homogenized for 10 s in and heated until 95 °C for 15 minutes in a shaking water bath; after that the dispersion was stored at 4 °C for 48 h and frozen at -20 °C for three cycles of days and then thawed in a bath at 30 °C, then centrifuged for 10 min. The amounts of gel before the centrifugation (gel mass) and water exudate (supernatant mass) were determined gravimetrically and the percentage of syneresis was calculated as follows:

$$\text{Syneresis } (\%) = (\text{supernatant mass})/(\text{gel mass}) \times 100 \qquad ...(1)$$

Degree of Hydrolysis of Native and Gelatinized Starch

For hydrolysis analysis, 1% w/v starch suspension was incubated at 37 °C with pancreatic amylase, samples were taken at 0, 10, 20, 30, 40, 50, and 60 minutes, and sugars were analyzed using the 3,5 dinitro salicylic acid (DNS) method.[26]

Water Holding Capacity (WHC)

The water holding capacity of the samples was determined following the method described by Yamazaki,[27] modified by Medcalf.[28] Briefly, a suspension of 0.15% w/w of starch in distilled water was prepared, and stirred for 30 min. After that the suspension was centrifugate at 3000 x g for 15 min. Then, the supernatant was removed and draining for 10 min.

Solubility Index

Starch solubility was measured following the procedure described by Jiang *et al*.[29] with some modifications. Briefly, a suspension of 1% w/w of starch in distilled water was prepared. The suspensions were heated at 25, 65, and 90 °C in a water bath with constant stirred. Then the suspension was cooled to 25 ºC and centrifuged at 3000 rpm for 15 min. The supernatant was dried at 110 °C until a constant weight. The Solubility idex was calculated using Equation 2:

Solubility index (%)=(Weight of dried supernatant)/(Weight of the sample) × 100 ...(2)

Statistical Analysis

Data were analyzed with unidirectional ANOVA using Statgraphics software (version centurión XVI) to determine statistically significant differences ($p < 0.05$) between samples. All tests were carried out in triplicate.

Results

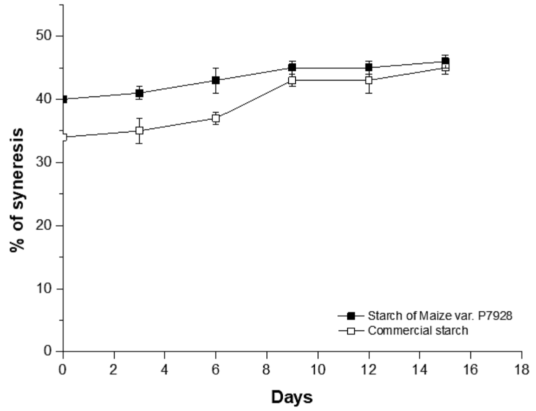

Fig. 1: Percentage (%) of syneresis of starch from corn var. P-7928 and commercial starch

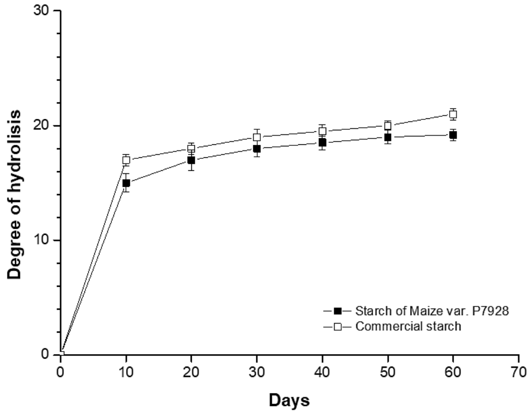

Fig. 2: Hydrolysis degree of starch from corn var. P-7928 and commercial starch

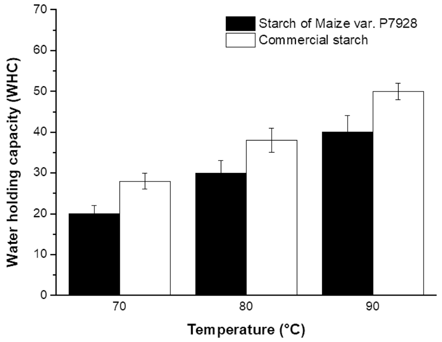

Fig. 3: Water holding capacity of starch from corn var. P-7928 and commercial starch

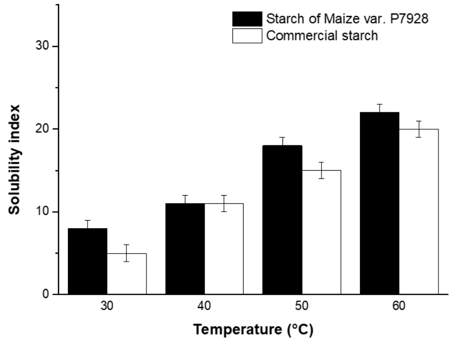

Fig. 4: Solubility of starch from corn var. P-7928 and commercial starch

Discussion

Syneresis Percentage

The variation of syneresis as a function of the time of starch from corn var. P-7928 and commercial starch are shown in Figure 1. The samples show a syneresis in the range between 35 and 45%, showing an increase with time. These highest values may be because the samples were prepared with 2% starch suspensions, that is, very diluted; thus, the gels will be less firm, so this result should be expected.

In food matrices, this phenomenon is reduced due to the higher concentration of starch, where the gel is firmer and has less tendency to lose water after freezing. The amount of water separated in the gel of the P-7928 variety is less compared to commercial starch, which makes it better when it comes to preparations with a relatively long shelf life that will be stored frozen. The syneresis process in frozen samples is due to the redistribution of water by the growth and then dissolution of ice crystals. The water retained by amylopectin is expelled from the intermolecular and intramolecular associations. This results in a separation of phases: one rich in starch (paste) and another deficient in it (liquid part). The higher value of commercial starch may be because it has a higher amylose content, so the linear chains are oriented in parallel and interact with each other by hydrogen bonds through their multiple hydroxyls, displacing water. P-7928 starch, which has more amylopectin, prevents the formation of these interchain hydrogen bonds because the branches prevent the association of parallel chains. The syneresis levels in the present work were higher than the data reported by de la Torre-Gutiérrez *et al*.[30] for corn starch with values less than 5%, Sathaporn Srichuwong *et al*. [31] for corn starch 35.4 %, waxy corn starch 9.6 %, millet starch 3.98%,[32] proso millet starch 26.00%,[33] native rice starch 2.81% and granular cold-water swelling rice starch 7.90% [34] and lowest than arrowhead starch 68.66%, chickpea starch 79.72%, gorgon fruit starch 76.77%, commercial lentil seed starch 78.25%, quinoa starch 75.65%, purple potato starch 74.37%, and sorghum starch 61.20%.[33]

Therefore, the food industry needs additives with low syneresis, due starches with this property readily absorb water. Mizrahi [35] explains that the increase of polymer concentration to constitute the gel allows to minimize the syneresis. A higher polymer concentration produce a higher the osmotic pressure, encouraging water to enter the gel. If the osmotic pressure is lower, the pressure of the network to return to its initial state will exceed the osmotic pressure, and syneresis will occur.

Degree of Hydrolysis

The percentage (%) of hydrolysis as a function of the time of starch from corn var. P-7928 and commercial starch are shown in Figure 2 with values greater than 16% and increasing with time. It is observed that at short hydrolysis times, amylase manages to break a few alpha 1-4 bonds, which translates into a low level of hydrolysis, while at 60 minutes of reaction, the enzyme's effect allows the breaking of a greater number of bonds, reaching degrees of hydrolysis of up to 19.2% for commercial starch and 21% for P-7928 starch, which are still considered low because the action of amylase on the whole granule is very slow. , because of the arrangement of the amylose and amylopectin molecules present in it. The resistance to attack by enzymes on starch granules depends on the X-ray diffraction pattern presented by their granules, classified into types A, B, and C, where type A is the most susceptible and to which cereal starches belong. Therefore, it is recommended to cook foods containing starch, as well as animal feed, if you want to achieve a better weight gain. The resistance of commercial starch is slightly higher compared to P-7928 starch, which may be influenced by the presence of anions and cations, as well as by the number of branches of the amylopectin chains, which makes the attack of the enzyme difficult.

The data obtained in this study were much higher than the data reported by Bhattacharya and Hanna (1985)[36] with values of 4.45% and 3.82% of improvement in protein digestibility after extrusion of dry corn gluten meal and wet corn gluten meal, and lower than Madushani Wijethunga *et al*. [37] showed protein digestibility values for corn gluten meal 26.3%, and for starch treated with microwave 37.8%, extruded 30.1%, heated, 32.4% and baked 30.7%.

Water Holding Capacity (WHC)

The water-holding capacity represents the ability to hold water against gravity, depending on the morphology, molecular structure, amylose content, amorphous and crystalline regions, the size distribution of the granules, and the type of modification.[38]

WHC of starch from corn var. P-7928 and commercial starch are shown in Figure 3, which presents values of 20 and 28%, respectively, which gives a measure of the amount of water that can be added to this product when making a food formulation, as the yields would be higher. At higher temperatures, the WHC is higher because of the release of linear amylose chains that form a network that retains water. The results are related to those obtained for the percentage of syneresis. The starch's presents a ability to absorb water associate to high WHC, indicating that could be used as thickeners. Obtained results are according to Njintang *et al*. (2007)[39] where with WHC was correlated with the bulk density. In addition, hydrophilic properties are related with the presence of hydroxyl groups between the starch chains and allows the formation of covalent and hydrogen bonds with the water molecule.[40]

Solubility Index

The water solubility index represents the amount of polysaccharides from starch granules after the addition of excess water.[41] Solubility profiles of starch from corn var. P-7928 and commercial starch are shown in Figure 5. The solubility increases with temperature, which can be explained because the heat increases the movements of the particles, decreasing their tendency to aggregate. The solubility index of the starches increased with the temperature. A similar result was obtained by Kaur *et al*.[42] for starch from wheat, rice, corn, barley, oats, sorghum, and millets and Mieles *et al*., for starch from mango kernel starch,[43] and lower than Dey *et al*.,[32] millet starch, Jingyi *et al*.,[33] for row head starch, gorgon fruit starch, chickpea starch, lentil seed starch, purple potato starch, millet starch, quinoa starch, and sorghum starch.

The increase in solubility with temperature is associated with starch granules continuously expanding until the paste temperature exceeds the gelatinization range. Heating starch in free water causes the destruction of the crystalline structure of the granules. Water molecules bind to the hydroxyl groups of amyloses through hydrogen bonds, increasing the solubility index. Then, low solubility can be associated with the degree of chain branching because solubility is the result of amylose leaching.[44] With increasing temperature, the expansion force increases above the gelatinization temperature, and many carbohydrates are filtered out of starch granules.

The water solubility index of starches is based on the interaction between starch within the amorphous and crystalline regions.[45] The change in water absorption index, water solubility index, and swelling power with temperature is associated with the gelatinization process, which implies a loss of molecular arrangement of the starch granule as a result of an increase in the system's kinetic energy, which allows water molecules to enter the starch granule.

Conclusion

Corn starch obtained from the P-7928 variety meets quality specifications. The residual bisulfite percentage of 0.1% meets the parameters established in the standards and is an indicator of the degree of purity of starch and the effectiveness of the washing process. The degree of syneresis is below the value of other commercial starches. The presence of anions and cations and the branches of the amylopectin chains hinder the catalytic action of the enzymes, which is why the hydrolysis percentages are low compared to those of other starches. The gelatinization process facilitates the enzymatic attack, increasing the percentage of hydrolysis to 98%. The water holding capacity (WHC) and the solubility index present acceptable values for this type of product. Physicochemical and functional properties of starch from corn var. P-7928 are useful for application in food systems and other industrial applications.

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This statement does not apply to this article.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Clinical Trial Registration

This research does not involve any clinical trials.

Permission to Reproduce Material from other Sources

Not Applicable.

Author Contributions

- **Ivan Gonzalez-Gongora:** Conceptualization, methodology, software, validation, formal analysis, investigation, project administration, funding acquisition.
- **Arnulfo Taron-Dunoyer:** Conceptualization, methodology, software, validation, formal analysis, investigation, data curation, writing—review and editing, visualization, supervision, project administration, funding acquisition.
- **Somaris Elena Quintana-Martinez:** Conceptualization, validation, formal analysis, investigation, data curation, writing—review and editing, visualization, funding acquisition.
- **Luis Alberto Garcia-Zapateiro:** Conceptualization, validation, formal analysis, investigation, writing—review and editing, visualization, supervision, project administration, funding acquisition.

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